Ideas after the SLAC/INT workshop

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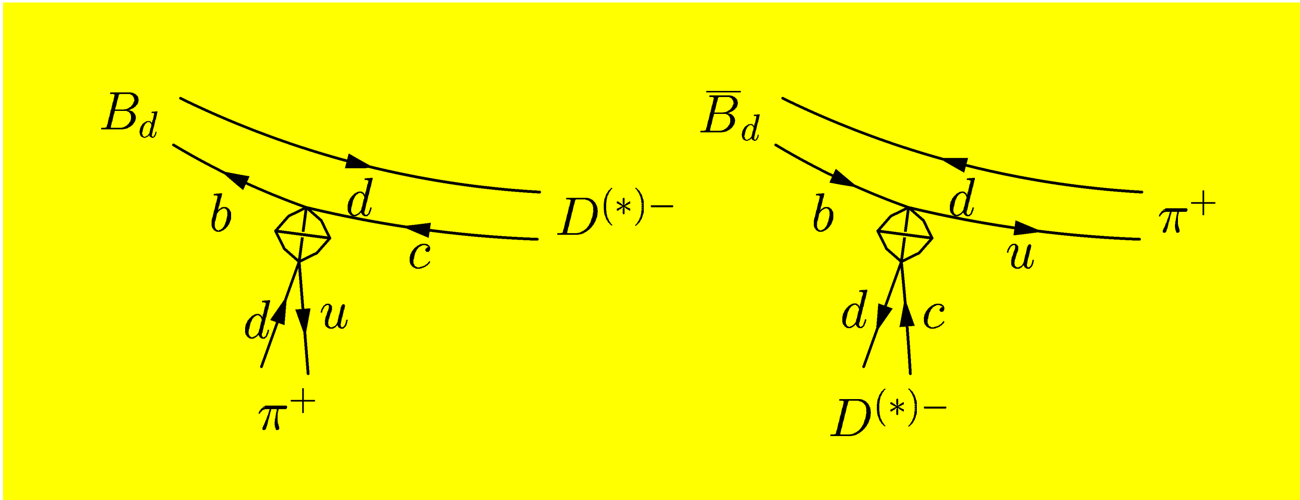
Fermilab

Outline

1. $2\beta + \gamma$ from $B_d(t) \to D^{(*)\pm}\pi^{\mp}$ or $B_d(t) \to D^{(*)\pm}\rho^{\mp}$
2. γ from $B \to D^{(*)0}K$
3. a_{CP} in $b \to s\overline{q}q$ penguin decays
4. Summary

1. $2\beta+\gamma$ from $B_d(t) \to D^{(*)\pm}\pi^{\mp}$ or $B_d(t) \to D^{(*)\pm}\rho^{\mp}$

The B factories try to extract $2\beta+\gamma$ from a tagged study of $B_d(t) \to D^{(*)\pm}\pi^{\mp}$



Unfortunately

$$r = \left| \frac{A(b \to u)}{A(b \to u)} \right| \sim 0.02$$

Neclecting terms of order r^2, the time evolution determines

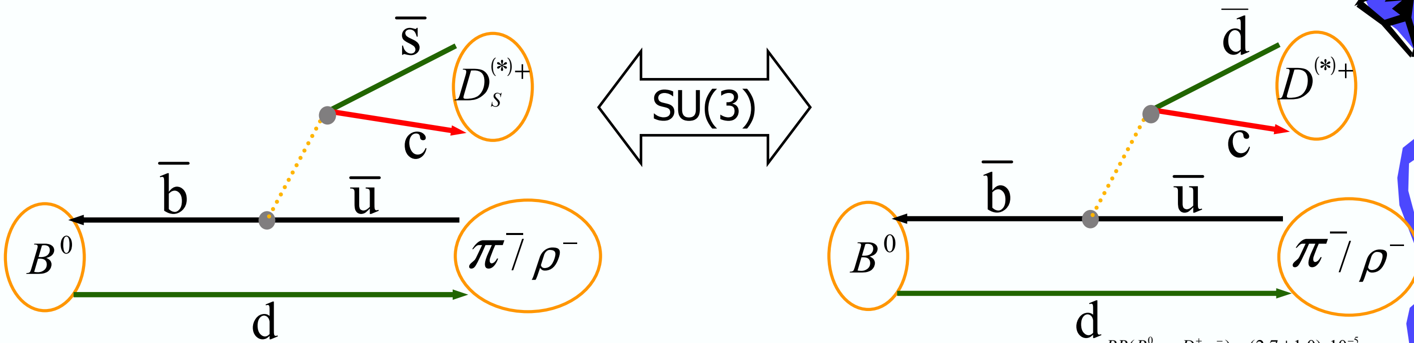
$$r \sin(2\beta+\gamma) \cos\delta \qquad \text{and} \qquad r \cos(2\beta+\gamma) \sin\delta$$

$\Rightarrow$ They need extra information on r.

Next slides: from Riccardo Faccini's talk at SLAC/INT workshop.

Determination of r_f

★ We currently use SU(3) to estimate r_f: $r_f = \left| \frac{A(B^0 \to D^{(*)+}\pi^- / \rho^-)}{A(\overline{B}^0 \to D^{(*)+}\pi^- / \rho^-)} \right|$



$$r_{(*)} \approx \sqrt{\frac{\mathcal{B}(B^0 \to D_s^{(*)+}\pi^-)}{\mathcal{B}(B^0 \to D^{(*)-}\pi^+)}} \left|\frac{V_{cd}}{V_{cs}}\right| \frac{f_{D^{(*)}}}{f_{D_s^{(*)}}}$$

Inputs:

$BR(B^0 \to D_s^+\pi^-) = (2.7 \pm 1.0)\cdot 10^{-5}$

$\frac{BR(B^0 \to D_s^{*+}\pi^-)}{BR(B^0 \to D^{*-}\pi^+)} = (5.4 \pm 3.6)\cdot 10^{-3}$

$BR(B^0 \to D_s^+\rho^-) < 1.9\cdot 10^{-5}$ @90%CL

$\left|\frac{V_{cd}}{V_{cs}}\right| = 0.2250 \pm 0.0027$

$BR(B^0 \to D^-\pi^+)$: PDG2004

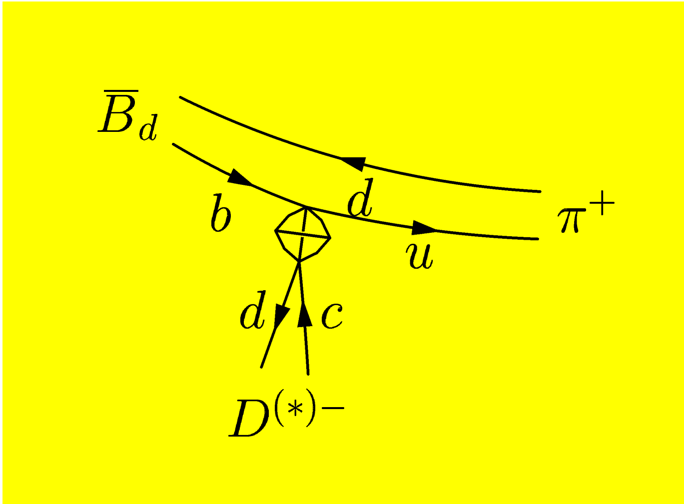
$\frac{fD_s}{fD} = 1.11 \pm 0.01$

$\frac{fD^*_s}{fD^*} = 1.10 \pm 0.02$

These errors are experimental only

$\boxed{r(D\pi) = 0.020 \pm 0.003 \qquad r(D^*\pi) = 0.015^{+0.004}_{-0.006} \qquad r(D\rho) = 0.003 \pm 0.006}$

They relate



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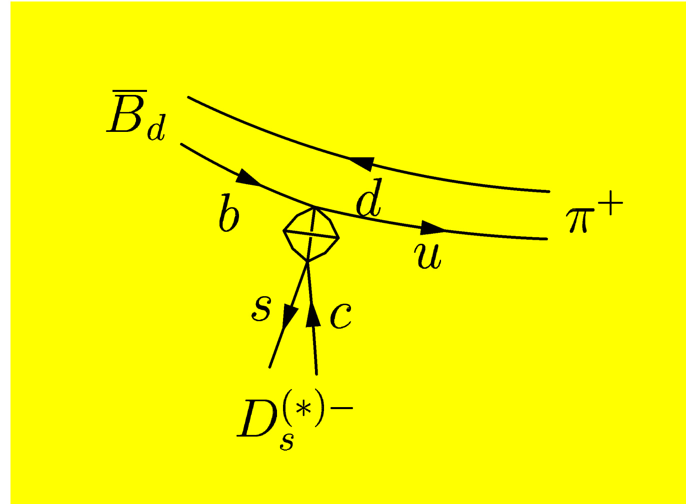
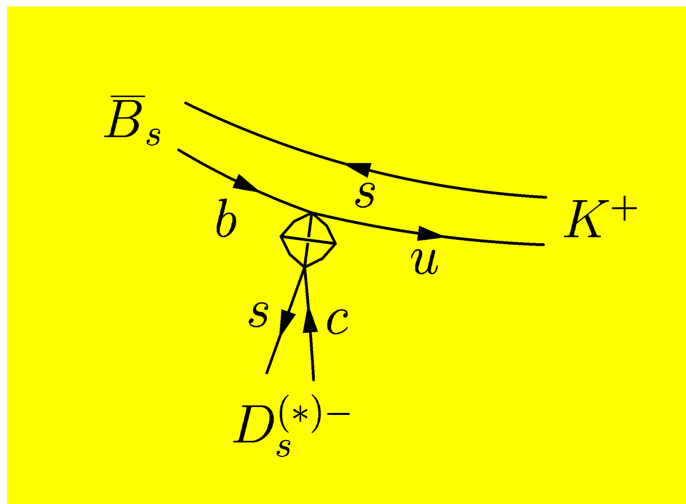


,

but a SU(3)$_\mathrm{F}$ transformation requires to exchange all d's with s's.

$\Rightarrow$ Need

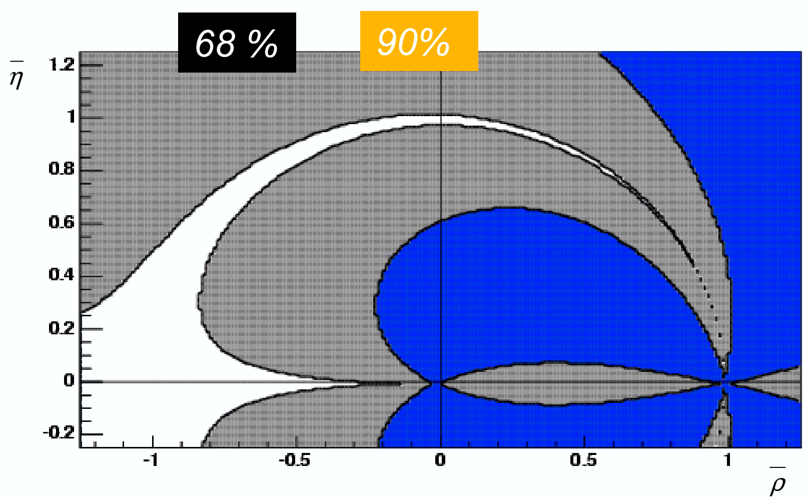


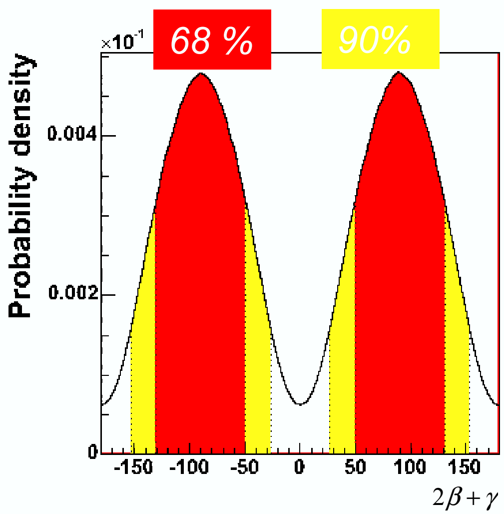
Can the Tevatron measure $Br(\overset{(-)}{B}_s \to D_s^{(*)-} K^+)$ or $Br(\overset{(-)}{B}_s \to D_s^{(*)-} K^{*+})$?
Also $Br(\overline{B}_s \to D^{(*)-} K^+)$ will shed light on SU(3)$_\mathrm{F}$ breaking.

Constraint on 2β+γ: bayesian

- Flat prior for 2β+γ, strong phases
- Gaussian prior for rf from SU(3) +30% flat (theoretical) error

$$\boxed{2\beta+\gamma=(88^{+40}_{-39})^o}$$

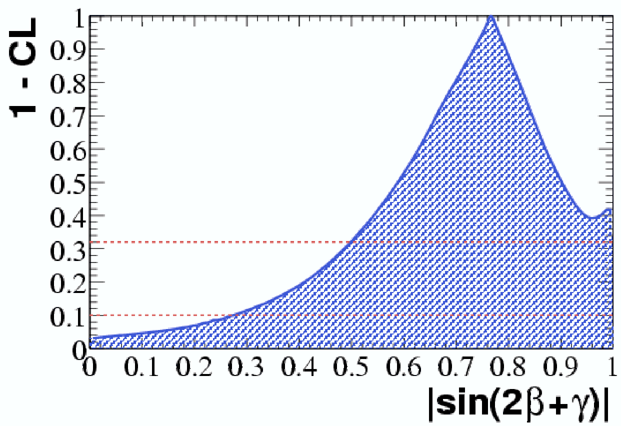


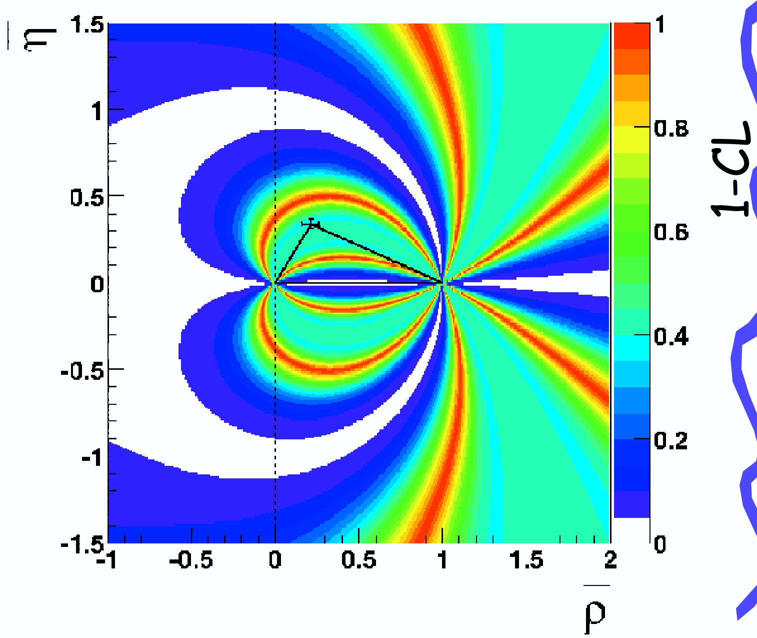


Constraint on sin(2β+γ): frequentistic

- Current WA + r_f +from SU(3) +30% theoretical

$|\sin(2\beta+\gamma)|>0.49$ @ 68%CL
$|\sin(2\beta+\gamma)|>0.27$ @ 90%CL

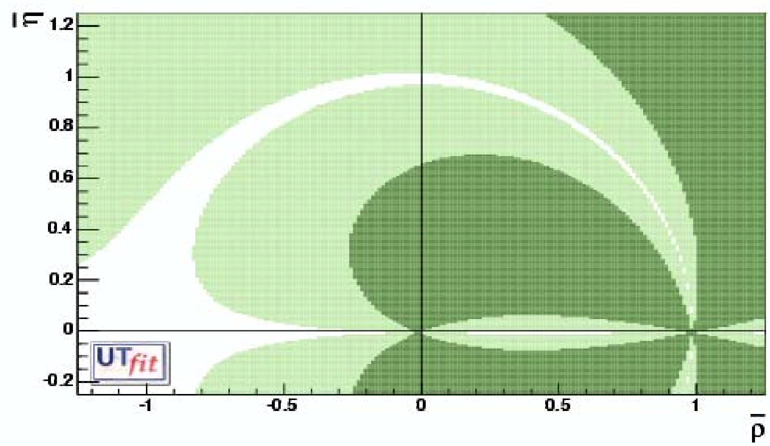




100% error on SU(3)

- Still dominated by exp errors. Would you sleep better with 100% error on 'r' derived assuming SU(3)?

$$\boxed{2\beta+\gamma=(89\pm43)^o}$$



was $2\beta+\gamma=(88^{+40}_{-39})^o$

What in 2008?

★ Assuming BaBar+Belle will have 2ab^{-1}

- Error computed scaling the statistical error with the luminosity and assuming:

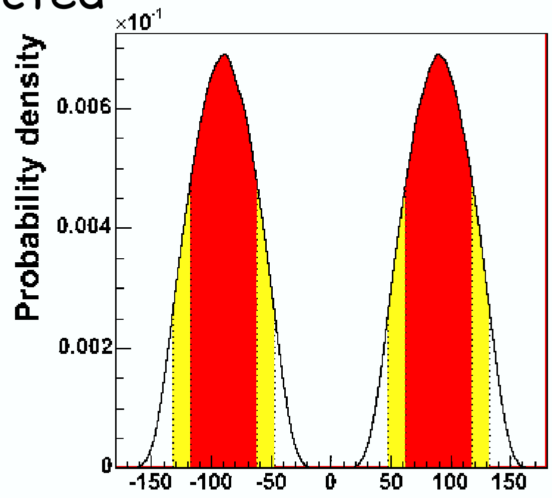
$\sigma_{syst}(a) = 0.009$

$\sigma_{syst}(c_{LEP}) = 0.013$

From BaBar partial $B \to D^*\pi$ result

- Central values assumed to deviate the same number of σ from expected a_f and $c_{f,LEP}$ values as now

$$a(D^*\pi) = -0.028 \pm 0.007$$
$$c_{LEP}(D^*\pi) = 0.001 \pm 0.011$$
$$a(D\pi) = -0.037 \pm 0.011$$
$$c_{LEP}(D\pi) = -0.018 \pm 0.018$$
$$a(D\rho) = -0.006 \pm 0.014$$
$$c_{LEP}(D\rho) = -0.038 \pm 0.021$$



★ Interpretation: current r_f from SU(3)

- Error on r_f starts to have an impact

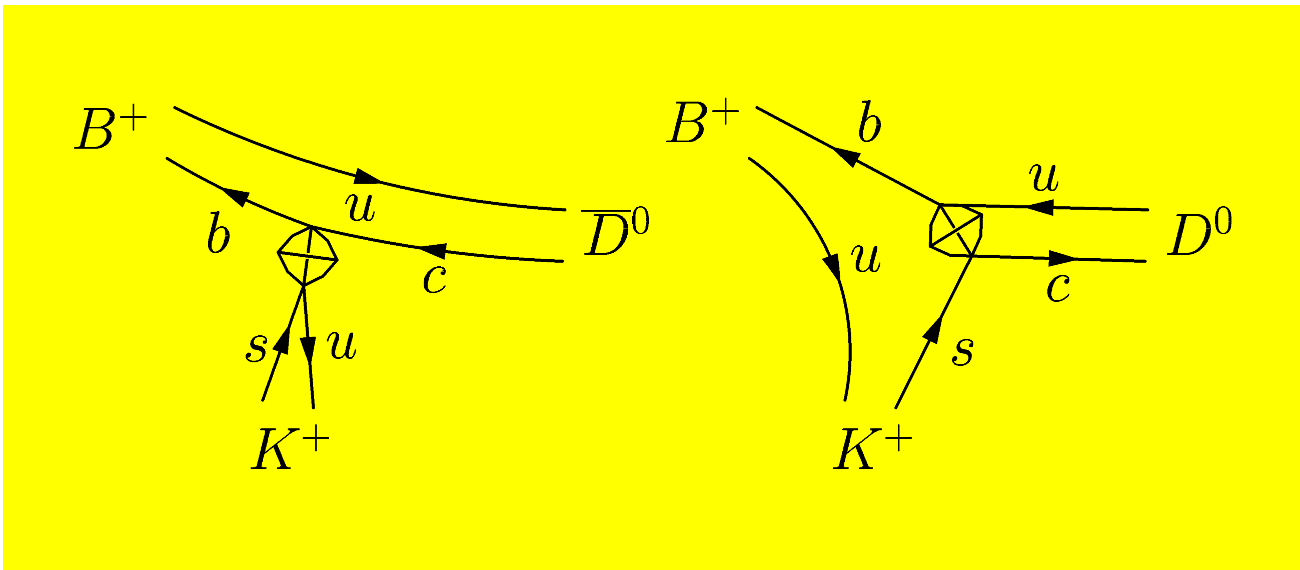
$$2\beta + \gamma = (88^{+29}_{-25})^o$$

2. γ from $B \to D^{(*)0} K$

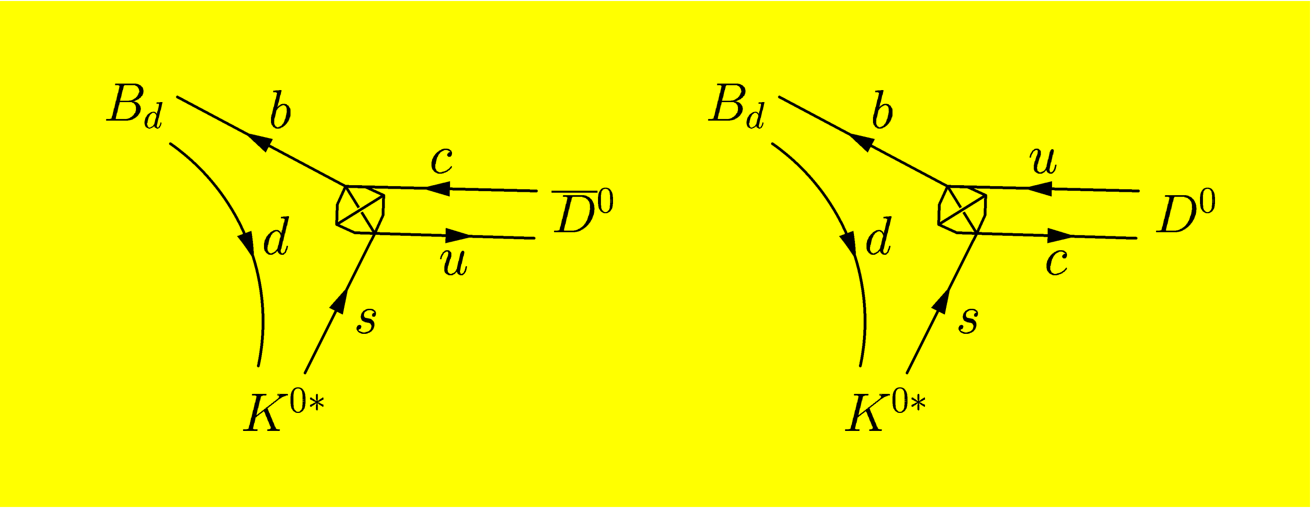
Need branching fractions only.

B factories can study:

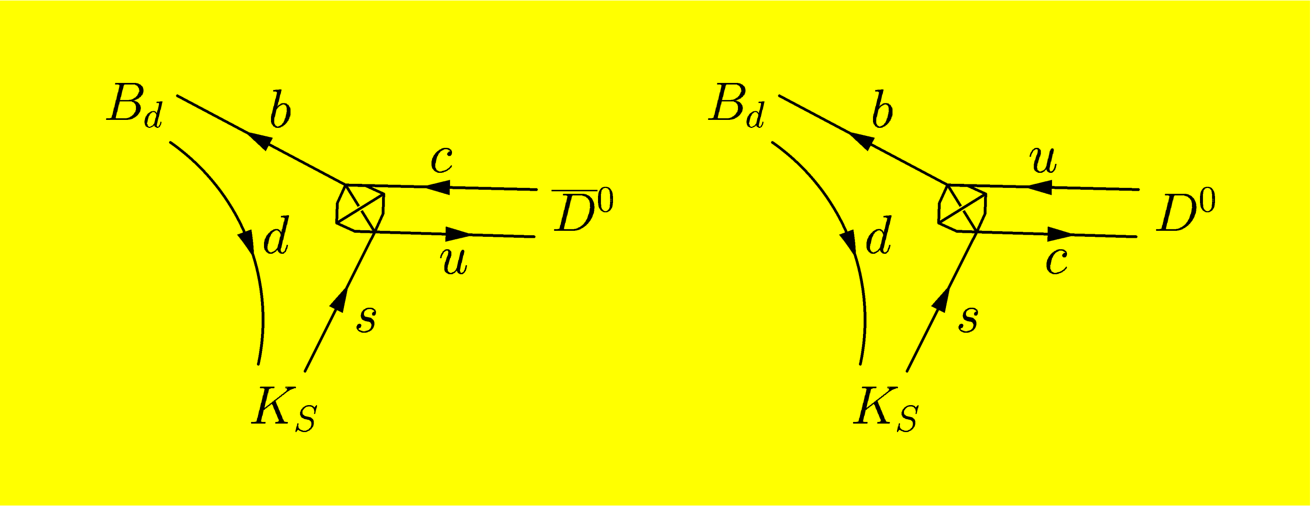
Gronau-London-Wyler:



Dunietz:



Gronau, Grossman, Shuhmaher, Soffer, Zupan:



In all cases the smaller amplitude $A(b \to u)$ has roughly the same size. In the GLW method the $A(b \to c)$ amplitude is much larger, but that does not help:

$$Br \propto |A(b \to c)|^2, \qquad\qquad a_{\rm CP} \propto r = \frac{|A(b \to u)|}{|A(b \to c)|}$$

Thus if $a_{\rm CP}$ is smaller by some factor x, one needs x^2 times as many events to get the same relative accuracy, compensating the gain in Br.

All methods require to study different $\overset{(}{\overline{D^0}}\overset{)}{} \to f$ decays in the decay chain $B \to \overset{(}{\overline{D^0}}\overset{)}{} X$.

At the B factories a full Dalitz analysis of $\overset{(}{\overline{D^0}}\overset{)}{} \to K_s \pi^+ \pi^-$ is currently the best method.

Next slides: from Tim Gershon's talk at SLAC/INT workshop.

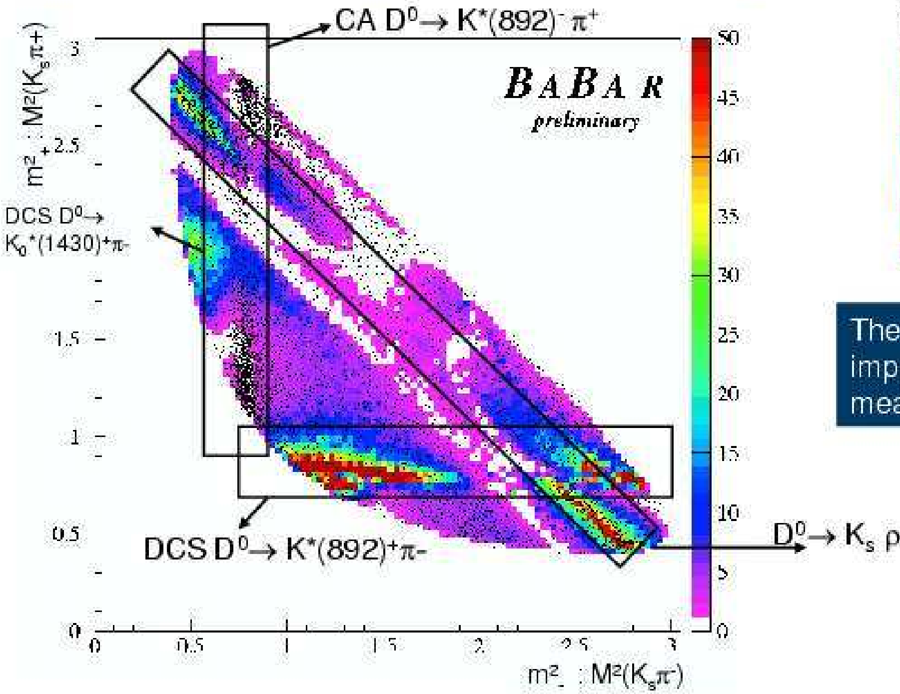
Sensitivity to γ

Generate a very large number of signal events

Compute the second derivative of the log(L) event by event : weight the event.

$$\sigma^2(\gamma) \sim \frac{1}{\frac{d^2 \ln(L)}{d\gamma^2}}$$

$BF[(B^\pm \to D^0K^\pm)(D^0 \to K^0\pi\pi)] = (2.2\pm0.4)10^{-5}$ *a priori* a large number of events....



points : weight = 1

$$\text{weight} = \frac{d^2 \ln(L)}{d\gamma^2}$$

The highest the weight the more important the event for γ measurement

$r_B=0.12$

$\gamma=70°$

$\delta=180$

Dalitz model as fitted on the tagged D^0 sample

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Results

Belle (275 M BB pairs)

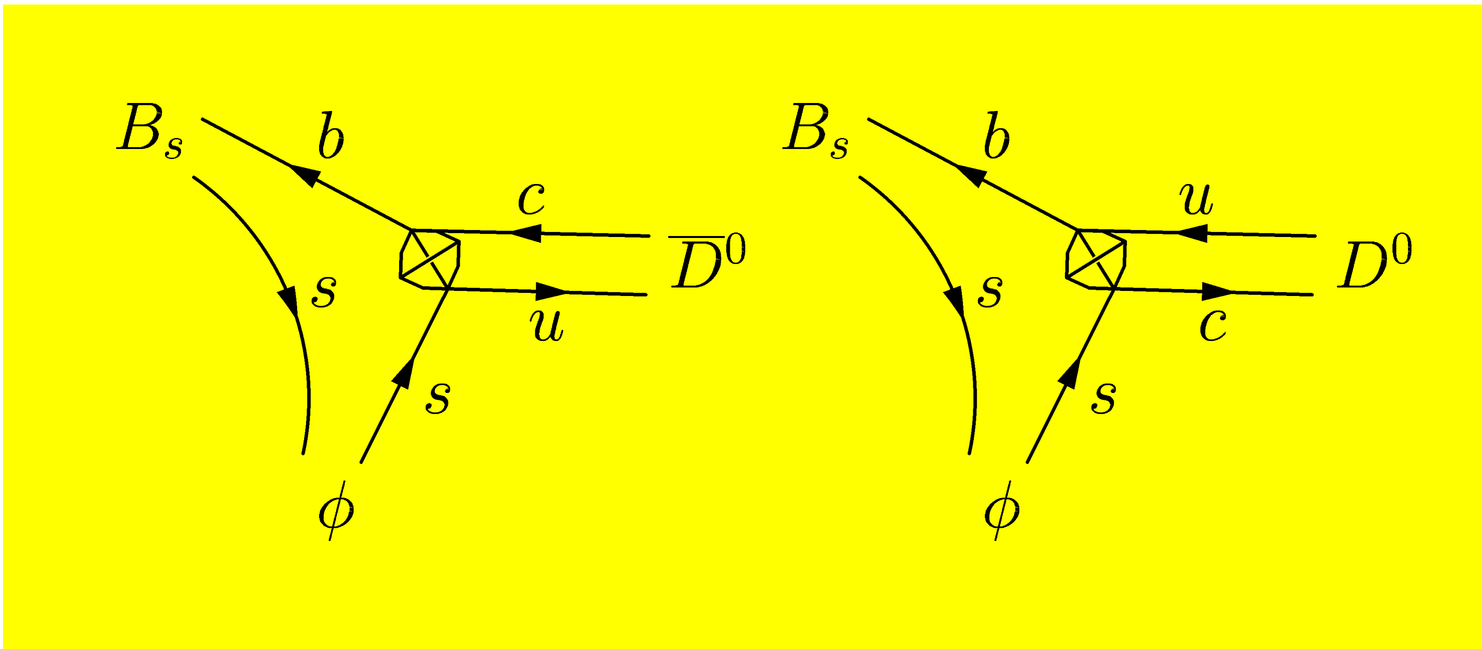
$$\phi_3 = 68^{+14}_{-15} \pm 13 \pm 11$$

BaBar (227 M BB pairs)

$$\gamma = 70 \pm 31^{+12}_{-10}{}^{+14}_{-11}$$

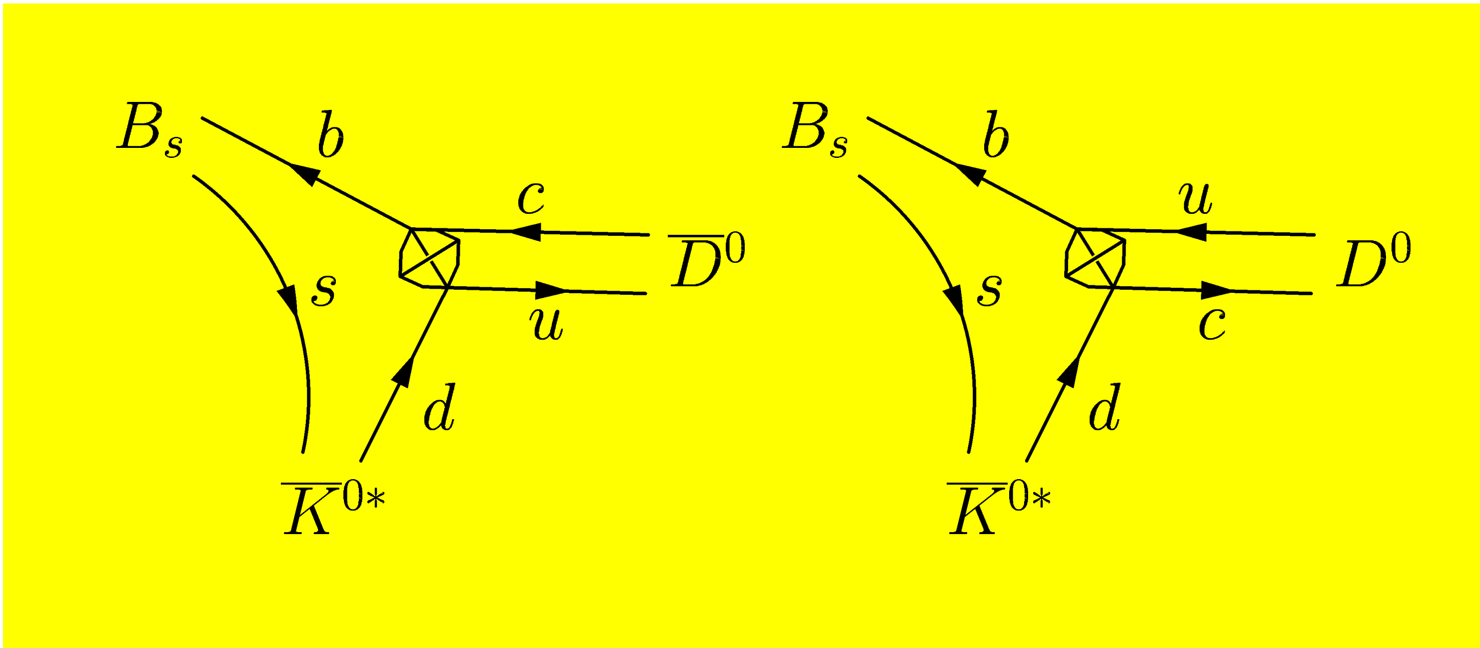
Only at the Tevatron one can measure γ from B_s decays:

Gronau, Grossman, Shuhmaher, Soffer, Zupan:



See my Chicago Flavor talk of April 22, 2005:

1 $\qquad\qquad$ $R_u \lambda^2$



$\overline{D^0} \to K^- \pi^+$ $\qquad\qquad$ $D^0 \to K^- \pi^+$

λ^2 $\qquad\qquad$ 1

These measurements of γ from tree-tree interference are modular: One can combine information from different measurements, one can add knowledge gained from new $\overset{(-)}{D^0} \to f$ decays which become accessible with increasing statistics. All decays $B \to \overset{(-)}{D^0}[\to f]X$ decays involve three hadronic parameters related to $B \to \overset{(-)}{D^0}X$ and one strong phase δ_f related to $\overset{(-)}{D^0} \to f$. Since e.g. the same $\delta_{K^-\pi^+}$ enters $B^+ \to \overset{(-)}{D^0}[\to K^-\pi^+]K^+$, $\overset{(-)}{B}_d \to \overset{(-)}{D^0}[\to K^-\pi^+]K_S$, $B_s \to \overset{(-)}{D^0}[\to K^-\pi^+]\overline{K}^{0*}$ and moreover $\delta_{K^-\pi^+}$ can be measured by CLEO-c, the combination of different measurements helps to overconstrain the hadronic parameters involved.

Another example:
$Br(\overset{(-)}{B}_d \to \overset{(-)}{D^0}[\to K^\pm\pi^\mp]K_S)$ and $Br(\overset{(-)}{B}_d \to \overset{(-)}{D^0}[\to K^{*\pm}K^\mp]K_S$ are not sufficient to determine γ, because one has 4 measurements with 5 parameters. Including $Br(\overset{(-)}{B}_s \to \overset{(-)}{D^0}[\to K^\pm\pi^\mp]\phi)$ and $Br(\overset{(-)}{B}_s \to \overset{(-)}{D^0}[\to K^{*\pm}K^\mp]\phi)$ adds 3 more parameters and 4 more measurements, and one can solve for γ.

Recommended:

http://www.int.washington.edu/talks/WorkShops/int_05_1/People/Grossman_Y/yuval-grossman_RDFTNS.pdf

http://www.int.washington.edu/talks/WorkShops/int_05_1/People/Soni_A/soni_talk.pdf

3. $a_{\rm CP}$ in $b \longrightarrow s\bar{q}q$ penguin decays

The mixing induced CP asymmetries in $b \longrightarrow s\bar{q}q$ decays show a promising deviation from the Standard Model.

Next slides: from Andreas Höcker's and Matthias Neubert's talks at SLAC/INT workshop.

Confronting Loop and Tree Decays

- The charmonium measurement: $\sin 2\beta = 0.725 \pm \underbrace{0.037}_{0.033_{[\text{stat-only}]}}$ HFAG, Winter 2005
  - Theory uncertainty ? Mannel at CKM 2005

    $\Delta S_{[c\bar{c}]} \equiv \sin 2\beta_{\text{eff}} - \sin 2\beta = (-2.2 \pm 2.2) \times 10^{-4}$

- Conflict with $\sin 2\beta_{\text{eff}}$ from *s*-penguin modes ?

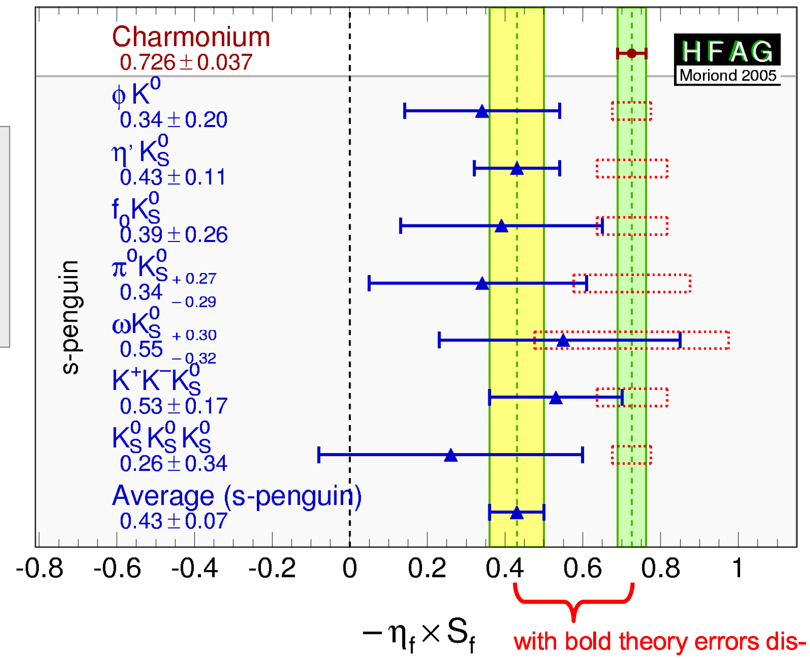
$$\langle \sin 2\beta_{[s\text{-peng}]} \rangle - \sin 2\beta_{[c\bar{c}]} = \underbrace{-0.30 \pm 0.08}_{3.7\sigma}$$

$$\langle \sin 2\beta_{[\phi/\eta'/2K_S]} \rangle - \sin 2\beta_{[c\bar{c}]} = \underbrace{-0.33 \pm 0.10}_{3.3\sigma}$$

  - Theory uncertainty ?

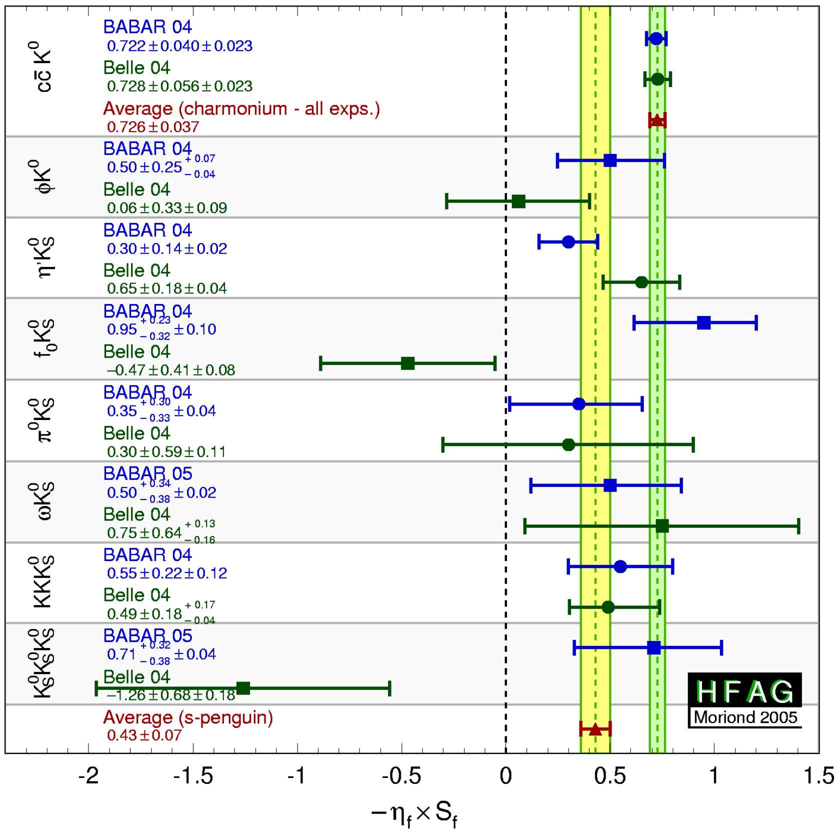
    what is $\Delta S_{[s\text{-peng}]}$? positive ?

WG4 at CKM 2005 and today's discussion



with bold theory errors discrepancy reduces to ~ 3σ

Comparison BABAR vs. Belle



Moriond 2005

Averages:

BABAR : CL = 0.62

Belle : CL = 0.05

both : CL = 0.15

SLAC/INT Workshop, Seattle 2005 — A. Höcker – $\sin 2\beta_{eff}$ with *s*-penguin decays — 7

The Experimental Program for $\sin 2\beta_{\mathrm{eff}}$

Mode	*CP*	Tot. error Belle $\mathcal{L} \sim 253\ \mathrm{fb}^{-1}$	Tot. error BABAR $\mathcal{L} \sim 195\text{-}212\ \mathrm{fb}^{-1}$	$\langle\Delta(\mathrm{SM})\rangle$ [in σ]	Error estimate at 2 ab^{-1}	Syste-matics	Max. central value for 5σ deviation at 2 ab^{-1}	Quality [naïve theoretical cleanliness]
ϕK^0	–1	0.34	0.26	– 1.9	0.10	small	0.22	☻ ☻ ☻
$\eta' K^0$	–1	0.18	0.14	– 2.6	< 0.05	small	0.45	☻ ☻ (☻)
$f_0(980)K^0$	+1	0.42	0.29	– 1.3	< 0.12	Q2B	0.12	☻ ☻
$K_S K_S K^0$	±1	0.71	0.36	– 1.4	< 0.16	vertex	– 0.08	☻ ☻ ☻
$K^+K^-K^0$	~+1	0.25	0.25	– 1.1	< 0.08	*CP*	0.31	☻ (☻)
$\pi^0 K_S$	–1	0.60	0.32	– 1.4	0.13	vertex	0.07	☻
ωK^0	–1	0.66	0.36	– 0.6	< 0.15	small	– 0.03	(☻)
$\rho^0 K^0$	–1	-	-	?	?	Q2B	?	(☻)
ηK_S	+1	-	-	?	?	vertex	?	-
Average	-	0.39 ± 0.11	0.45 ± 0.09	– 3.7	< 0.034	ok	0.53	☻ ☻

Basic relations

- Decay amplitudes:

$$\boxed{A(\bar{B} \to f) = V_{cb}V_{cs}^* \, a_f^c + V_{ub}V_{us}^* \, a_f^u \propto 1 + e^{-i\gamma} \, d_f}$$

where:

$$d_f = \epsilon_{\mathrm{KM}} \frac{a_f^u}{a_f^c} \equiv \epsilon_{\mathrm{KM}} \hat{d}_f \quad \text{with} \quad \epsilon_{\mathrm{KM}} = \left| \frac{V_{ub}V_{us}^*}{V_{cb}V_{cs}^*} \right| \sim 0.025$$

- Parameter ε_{KM} determines smallness of the effects

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Basic relations

- CP asymmetries:

$$\Delta S_f \equiv \frac{2\,\mathrm{Re}(d_f)\cos(2\beta)\sin\gamma + |d_f|^2\left(\sin(2\beta+2\gamma)-\sin(2\beta)\right)}{1+2\,\mathrm{Re}(d_f)\cos\gamma + |d_f|^2}$$

$$A_{\mathrm{CP},f} \equiv -C_f = \frac{2\,\mathrm{Im}(d_f)\sin\gamma}{1+2\,\mathrm{Re}(d_f)\cos\gamma + |d_f|^2}.$$

  - If d_f is small, then both involve independent hadronic parameters

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Results: 200000 parameter scans

- Require that BRs are reproduced within 3σ

Mode	ΔS_f (Theory)	ΔS_f [Range]	Experiment [3] (BaBar/Belle)
$\pi^0 K_S$	$0.07^{+0.05}_{-0.04}$	$[+0.02, 0.15]$	$-0.39^{+0.27}_{-0.29}$ $(-0.38^{+0.30}_{-0.33}/-0.43^{+0.60}_{-0.60})$
$\rho^0 K_S$	$-0.08^{+0.08}_{-0.12}$	$[-0.29, 0.02]$	—
$\eta' K_S$	$0.01^{+0.01}_{-0.01}$	$[+0.00, 0.03]$	$-0.30^{+0.11}_{-0.11}$ $(-0.43^{+0.14}_{-0.14}/-0.07^{+0.18}_{-0.18})$
ηK_S	$0.10^{+0.11}_{-0.07}$	$[-1.67, 0.27]$	—
ϕK_S	$0.02^{+0.01}_{-0.01}$	$[+0.01, 0.05]$	$-0.39^{+0.20}_{-0.20}$ $(-0.23^{+0.26}_{-0.25}/-0.67^{+0.34}_{-0.34})$
ωK_S	$0.13^{+0.08}_{-0.08}$	$[+0.01, 0.21]$	$-0.18^{+0.30}_{-0.32}$ $(-0.23^{+0.34}_{-0.38}/+0.02^{+0.65}_{-0.66})$

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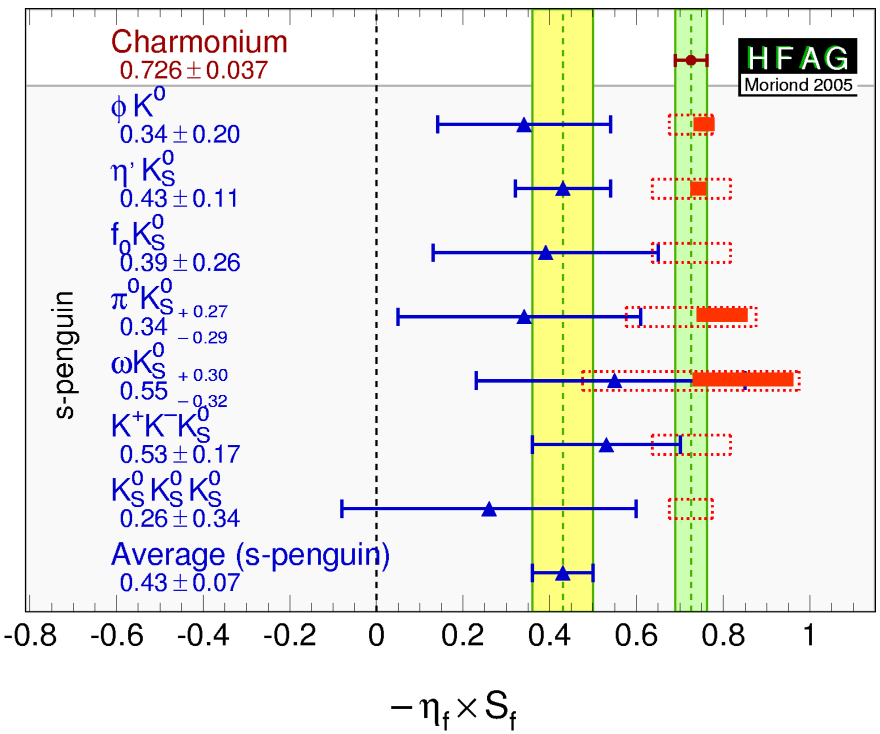
Theory vs. Experiment



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Conclusions

- Except for ρK_S, QCDF predicts positive ΔS_f, enforcing the disagreement with data
- Very small effect and uncertainty for ΦK_S and $\eta' K_S$, reliable predictions
- Enhancement of color-suppressed amplitudes (C, $P_{EW,C}$) suggested by $\pi\pi$ and πK data, if true, would not change results significantly

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Implications for Tevatron physics

- B_s physics allows to study some pure penguin $b \to s\bar{d}d$ decays: $B_s \to K_S K_S$, $B_s \to K^{0*} K_S$ and so on.
- Look for direct CP violation (need to be lucky with non-zero strong phase). There is no advantage here in B_s over B_d or B^+.
- The lifetime information in $B_s \to \phi\phi$, $B_s \to K_S K_S$, $B_s \to K^+ K^- \ldots$ is sensitive to the potentially new CP phase in $b \to s\bar{q}q$ (see my Chicago Flavor seminar of February 25, 2005).
- A study of $B_s \to \phi\rho$ allows to find out to which extent the new physics amplitude violates isospin.

- In the longer term tagged studies of mixing-induced CP asymmetries in B_s decays are helpful, because in all possible $b \to s\overline{q}q$ decays $B_s \to f$ and $\overline{B}_s \to f$ interfere! (The final state has quark contents $s\overline{s}q\overline{q}$.) The corresponding B_d decays studied by BaBar and BELLE all have a K_S (or K_L) in the final state to allow for the interference of $B_d \to f$ and $\overline{B}_d \to f$. (The final state has quark contents $(d\overline{s} \pm s\overline{d})q\overline{q}$).
  By the end of Run-II can we hope for a tagged study of e.g. $B_s \to K^+K^-$?

4. Summary

- The measurement of $\sin(2\beta+\gamma)$ from $B_d(t) \to D^{(*)\pm}\pi^{\mp}$ and $B_d(t) \to D^{(*)\pm}\rho^{\mp}$ at the B factories profits from the knowledge of the branching fractions $Br(\overset{(}{\overline{B}}\overset{)}{}_s \to D^{(*)-}_{(s)} K^{+})$ and $Br(\overset{(}{\overline{B}}\overset{)}{}_s \to D^{(*)-}_{(s)} K^{*+})$.

- The determination of γ from $B \to \overset{(}{\overline{D^0}}\overset{)}{} X$ is modular and profits from the combination of different measurements at BaBar, BELLE, CDF and CLEO-c. Go for $\overset{(}{\overline{B}}\overset{)}{}_s \to \overset{(}{\overline{D^0}}\overset{)}{}\phi$!

- The $b \to s\overline{q}q$ CP puzzle found at the B factories can be studied from the lifetimes in B_s decays, if $\Delta\Gamma_{B_s}$ is large. All $b \to s\overline{q}q$ decays of the B_s meson are sensitive to the interference of $B_s \to f$ and $B_s \to \overline{f}$.